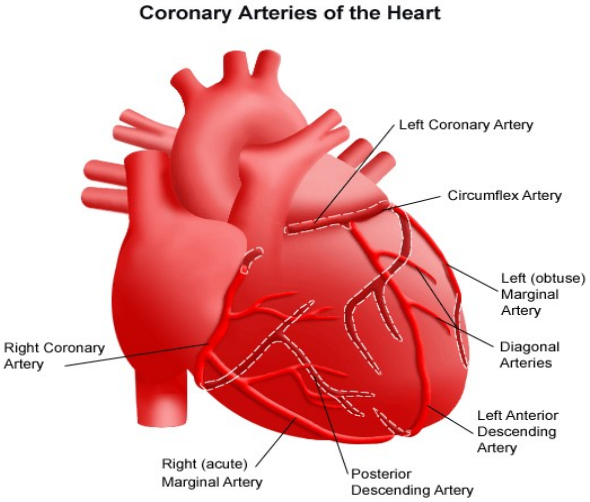
Coronary, cerebral and cutaneous circulations

By the end of this lecture the student will be able to:

- Describe the coronary blood flow and its phasic changes during the cardiac cycle.
- States the relative importance of local metabolic and neural control of coronary, cerebral and skin blood flow
- Describe the regulation of the coronary, cerebral and skin blood flow.
- Apply the information studied in this section to solve a clinical problem or explain clinical case.

Coronary circulation



I-characters of coronary blood flow:

1-**During rest**: 4% of cardiac output= 250 ml/min.

2- **High oxygen extraction ratio** is70%, low venous oxygen reserve

So, during exercise: increased coronary blood flow is the only way to increase oxygen supply to heart

3- High capillary density one capillary/one muscle fiber

4- Coronary vessels are functionally end arteries with no sufficient anastomosis. Acute coronary obstruction causes myocardial infarction because cardiac muscle is an aerobic muscle.

II- Coronary blood flow regulation:

1- Coronary autoregulation: mainly metabolic (chemical) mechanism, myogenic

2- Mechanical factors:

- A- Phasic changes during the cardiac cycle
- B-Aortic pressure
- C-Regional distribution of blood flow
- D- Heart rate

3- Neural factors

4- Humoral factors

1-Coronary autoregulation:

- **Definition:**
  - Intrinsic capacity to maintain constant blood flow in spite of the changes in coronary perfusion by altering the vascular diameter
  - Most prominent over the pressure range (about 60 to 140 mm Hg).
- **Mechanism:**
  - Myogenic and metabolic theory
  - ***Local metabolism is the primary controller of coronary flow.***
- Decrease coronary perfusion or increase cardiac activity will lead to:
  - ***Decrease oxygen (oxygen demand)***
  - ***Increased: Co2, K+ , Adenosine, H+***
  - **Adenosine** is a potent vasodilator and it increases the blood flow to cardiac muscle
- **Response:** Dilatation of coronary vessels and increased blood flow to cardiac muscle

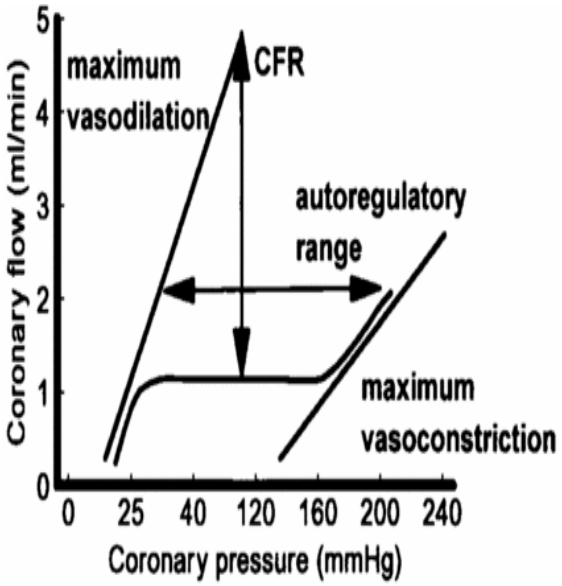


Figure (1): Autoregulation of coronary vessels

2- Mechanical factors:

A- Phasic changes during the cardiac cycle:

- **During systole**

Intramyocardial pressure increases and compresses the coronary vessels, coronary blood flow decreases (briefly reversed)

- **During diastole**

Intramyocardial pressure decreases, coronary blood flow increases

- Left coronary artery maximal flow occurs during isovolumetric relaxation phase. Because aortic pressure Higher than left ventricle pressure + Reactive hyperemia.
- Right coronary artery maximal flow occurs during rapid ejection phase because aortic pressure Higher than right ventricle pressure._

B- Aortic pressure:

- Coronary blood flow is directly proportionate to the diastolic aortic pressure
- Coronary flow decreases in shock, aortic incompetence

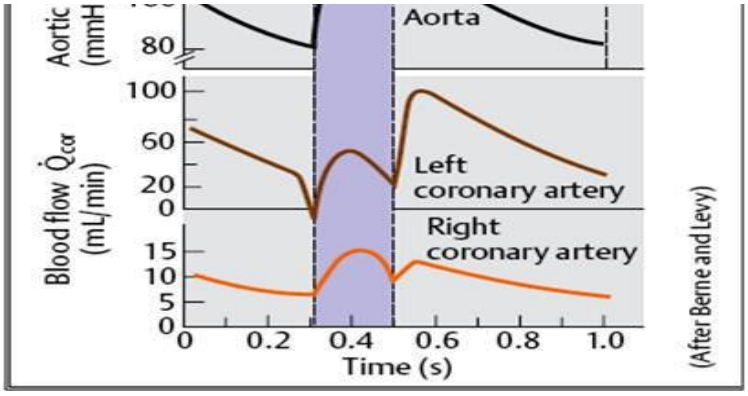


Figure (2): Changes in coronary flow during cardiac cycle

C-Regional distribution of blood flow:

- **Subendocardial layer:**

The increase in the extravascular component of coronary resistance (high intramyocardial pressure) is sufficient to cause cessation of blood flow through the subendocardial layer during isovolumetric contraction phase.

Subendocardial layer is more susceptible to ischemia because from the geometry and mechanics of ventricular contraction, they perform the greatest work in the development of tension and consume larger amounts of oxygen in addition to the great compressive resistance.

D- Heart rate:

- left ventricular coronary flow is reduced during tachycardia
- Because diastole is shorter when the heart rate is high

3-Neural factors:

- **Direct action**; sympathetic decreases coronary blood flow acting on alpha receptors
- **Indirect action:**
- Increasing metabolic activity with oxygen lack leads to vasodilatation

4- Humoral factors:

Catecholamines act on beta receptors causing coronary vasodilatation

Nitric oxide released from vascular endothelium Due to shearing forces due to increased coronary flow

Endothelial derived relaxing factor: increased coronary flow
Histamine: increased coronary flow

III-Clinical points:

Partial obstruction of the coronary artery by spasm or atherosclerosis causes angina pectoris, while complete lack of blood supply due to total occlusion of a coronary vessel causes myocardial infarction.

Main symptom:

- Pericordial, substernal pain, often referred to left arm, left shoulder radiates to the neck

Angina pectoris is differentiated from myocardial infarction by being recurrent short lived attacks of inadequate coronary blood flow during exertion or emotional tension associated with pain. Relieved by rest or nitrites.

Treated by :

A) Nitrites:

They decrease preload and afterload to meet oxygen requirements

B) Slight exercise:

Hypoxia and adenosine accumulation the most important coronary dilator and stimulate angiogenesis

Myocardial infarction:

Necrosis of the cardiac muscle fibers followed by fibrosis

- **ECG changes that accompany myocardial infarction;**
  - Raised ST segment: current of injury
  - Inverted T wave: ischemia
  - Deep Q wave: electric window

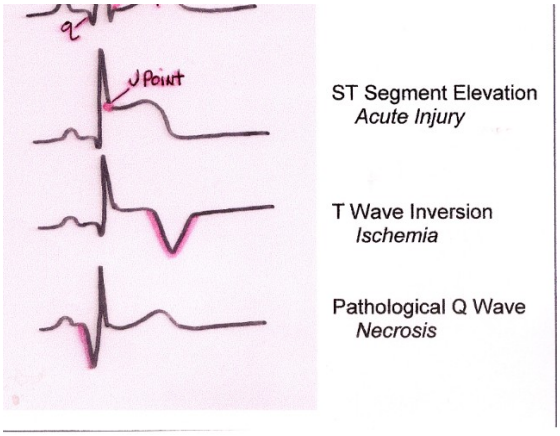


Figure (3) ECG changes with myocardial infarction

Cerebral circulation

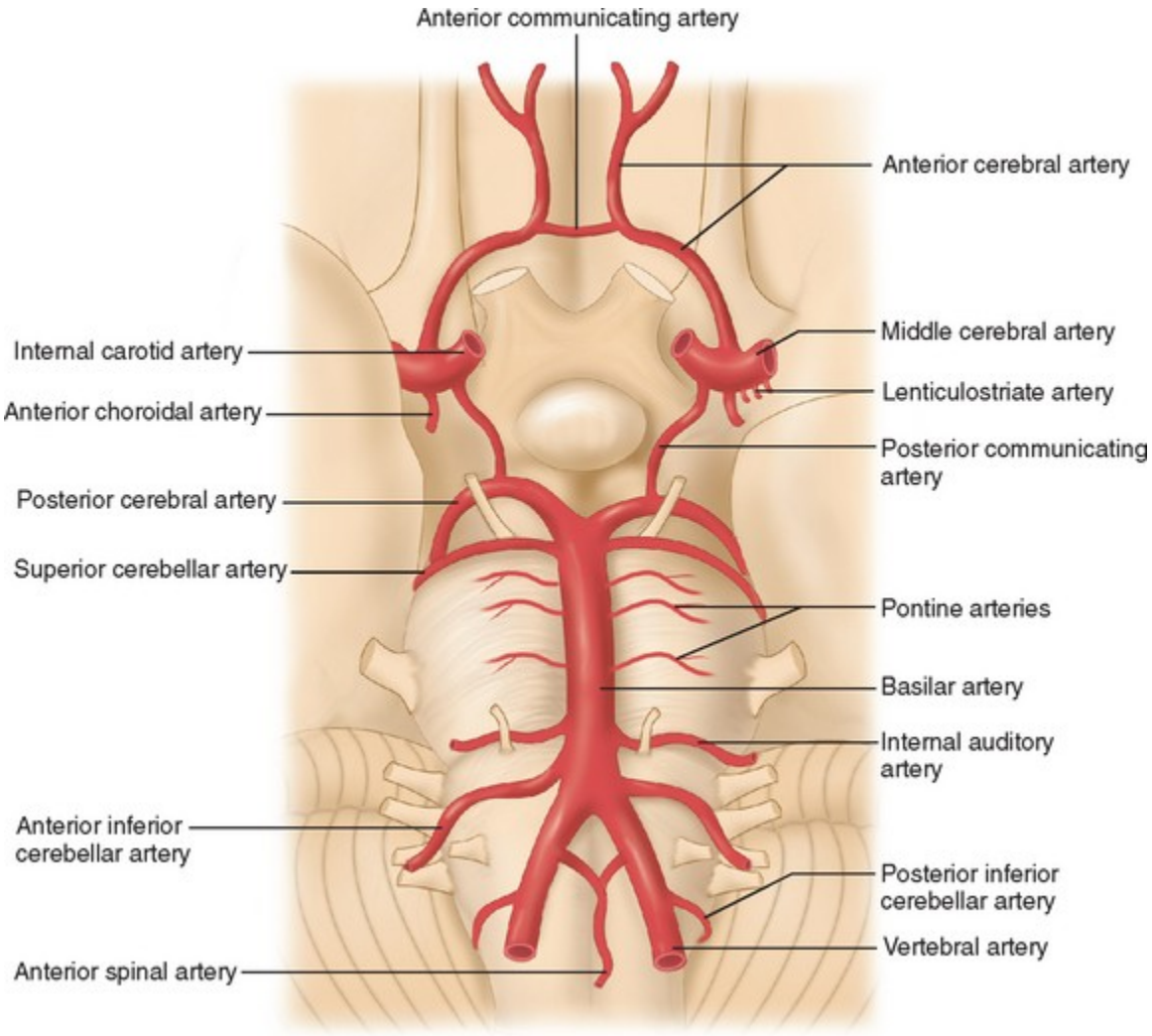


Figure (4): circle of willis suppling the brain

1-Characters of cerebral circulation:

1. Brain receives blood from the **basilar artery** and **internal carotid artery that form circle of Willis**
2. Each internal carotid supply ipsilateral hemisphere no crossing over
3. Cerebral arteries are end arteries
4. Brain has an aerobic metabolism and uses glucose as main energy source
5. Brain receives 13% of cardiac output (756 ml/min)
6. Total cerebral blood flow is constant, unchanged during sleep or mental activity
7. Regional variation: Coupling between local metabolic rate and CeBF: it increases in left motor cortex while voluntary clenching of right hand
8. Cerebral capillaries form the blood brain barrier
9. According to the ***"Monro-kellie doctrine:***

- **Brain tissue**, **cerebrospinal fluid (CSF)** and **cerebral blood vessels** are enclosed in the rigid skull with the overall volume kept constant
- **Brain tissue** is not compressible
- The cerebral arteries are compressed by increased intracranial pressure or cerebrospinal fluid pressure

2- Regulation of cerebral blood flow:

A. **Cerebral autoregulation**
B. **Chemical factors**
C. **Mechanical factors**
D. **Neural factors**

A- Cerebral autoregulation:

Definition:

The cerebral blood flow (CeBF) is kept nearly constant despite variations in perfusion pressure, range at MAP (60 – 140) mm Hg.

Mechanism:

- Myogenic: Vascular smooth muscles of cerebral arterioles respond to stretch by vasoconstriction
- Metabolic: CO2 is the main cerebral vessels dilator

B- Chemical regulation:

1) **Blood gases:**

1- Carbon dioxide:

- **The strong vasodilator, Most important determinant of cerebral blood flow**
- The **increase in PCO2** will **increase H+ ion concentration in CSF, hydrogen is a potent dilator.**
- Hyperventilation and wash out of carbon dioxide leads to decrease in cerebral blood flow, **dizziness, loss of consciousness**

2- Oxygen:

- Hypoxia increases cerebral blood flow by dilatation
- Effect of hypoxia starts when PO2 is less than 50 mmHg

2) **Metabolic products:**

The aim: to adjust regional CeBF to the metabolic neural activity

- **Hydrogen**
- **Potassium**
- **Adenosine: potent dilator**

3) **Nitric oxide:**

- It is a potent vasodilator. It has an important role in regulation of basal cerebral blood flow

Note: Systemic vasoconstrictors don't cross BBB

C- Mechanical regulation:

1. **The cerebral effective perfusion pressure** equals the difference between ABP at the head level and the venous pressure in internal jugular vein which is normally near zero.
2. **Cerebral blood flow depends on the balance between cerebral perfusion pressure and intracranial pressure (ICP)**

Increase CeBF	**Decrease CeBF**
Increase in ABP	**Increase in internal jugular venous pressure:** ➢ Decrease cerebral effective perfusion pressure ➢ Impair CSF drainage and increase CSF pressure and ICP
	Increase in intracranial pressure (ICP) normal 10-12 mmHg: Brain tumor or increase venous pressure

	CNS ischemic response	**Cushing reflex**
Stimuli	Decreased blood pressure< 50 mmHg	Increased intracranial pressure
	Cerebral arterial pressure < intracranial pressure	Intracranial pressure >Cerebral arterial pressure

	Decrease cerebral blood flow leads to s**evere oxygen lack, increased Co_2**
Center	Direct stimulation to ischemic neurons of **Pressor area of VMC** stimulates sympathetic adrenergic fibers **(α1)**
respon se	Strong vasoconstriction, hypertension and associated Bradycardia {**baroreceptor effect**}

3-Effect of the gravity:

- **Intra-arterial and intravenous pressures, extravascular CSF pressure (ICP), are balanced at all points in the cranium.**

In the upright position: the MAP at the brain level is lower by about 25 mm Hg, but the effective CPP is not reduced to the same extent because venous collapse is prevented in the skull and the VP and CSF pressure are both negative. So in the upright position there is about 20 % reduction of CeBF.

In upward acceleration:

Blood moves toward the feet leading to decrease in ABP at the head level, but also giving rise to a fall to a lesser extent in both the VP at the same head level and the intracranial pressure. CPP is partially maintained and so blood continues to flow to the brain.

In downward acceleration:

Blood moves toward the head, and the ABP at the level of the head is markedly increased. However, the simultaneous rise in both the VP and the ICP leads to external support and protection of small vessels against possible rupture due to the excessive rise in intravascular pressure.

D-Neural regulation:

- Neural control plays little role in regulation of cerebral blood flow.

- In hypertension sympathetic noradrenergic discharge produces strong vasoconstriction on large cerebral arteries.
- Aim: prevents the passive increase in blood flow and helps to protect the blood brain barrier

❖ **Note:**

- Increase **blood viscosity** increases **cerebral vascular resistance** and decreases cerebral blood flow.

Blood brain barrier

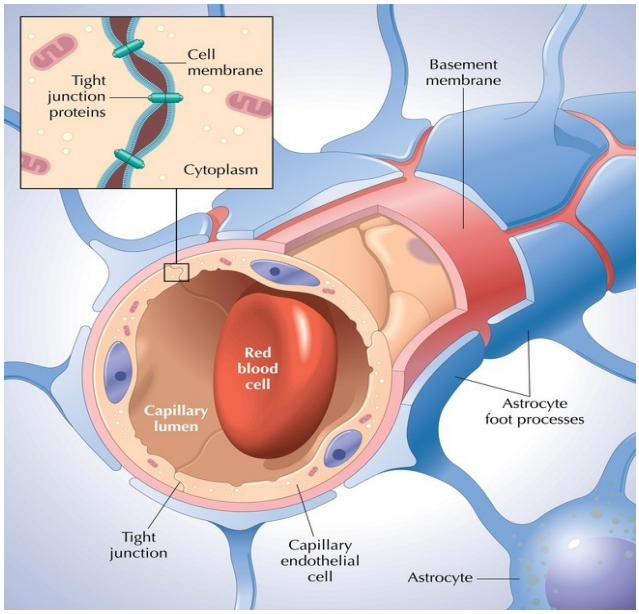


Figure (5): Blood brain barrier

- It separates the circulation from the brain
- **Formed of:**

1. Tight junctions between endothelial cells
2. Prominent basement membrane
3. Pericytes: maintain tight junction stability
4. The cytoplasmic foot processes of the astrocytes that surround vessels

- **Function:**

❖ Maintain constant ionic composition, PH in neural environment
❖ Protects brain from endogenous, exogenous toxins
❖ Prevents neurotransmitter escape to the blood stream

- **Permits** o_2, **co_2**, H_2o, lipid soluble substances as alcohol, ammonia, anesthetic drugs, steroid hormones.
- **Prevents** passage of proteins, hormones and bile pigments.
- Proteins transport is limited and depends on **vesicular transport.**
- Glucose uptake by facilitated diffusion insulin independent (GLUT 1).

Some brain parts lie outside the blood brain barrier and are called circumventricular organs.

Posterior pituitary	Secretes ADH, oxytocin
Area postrema contain Chemoreceptor zone	Initiates vomiting
Organum vasculosum of lamina terminalis contain osmoreceptors	control ADH secretion
Subfornical organ	Increase water intake

Cerebrospinal fluid

This is a clear fluid, that occupies the subarachnoid space (the interval between the arachnoid membrane and pia mater), and the ventricular system (right and left lateral ventricles, third ventricle, and fourth ventricle. The volume of CSF is about 150 ml.

Formation:

CSF is formed by the active secretion from the choroid plexuses in the four ventricles (The choroid plexus is a cauliflowerlike growth of blood vessels covered by a thin layer of epithelial cells, mainly in the two lateral ventricles)

Absorption:

Absorbed by bulk flow (depend on hydrostatic pressure) to venous sinus

Functions:

1.Protection the brain tissue from injury when jolted or hit

2. Rinsing the metabolic waste

3. Homeostatic regulation of the distribution of neuroendocrine factors, to which slight changes can cause problems or damage to the nervous system.

Cutaneous circulation

1-Cutaneous blood flow is mostly directed for thermoregulation (i.e helps to maintain a constant deep-body temperature despite changes in the ambient (external) temperature, more than for metabolism or nutrition of skin).

2-A-V shunts which are short wide vessels are important for temperature regulation

I-Regulation of cutaneous blood flow:

A. **Mainly neural:**

- Richly supplied by sympathetic vasoconstrictor nor-adrenergic fibers act on alpha receptors causing vasoconstriction (tonic vasoconstriction). It is regulated by baroreceptor reflex.
- Sympathetic cholinergic dilator fibers to sweat glands to stimulate sweating with active vasodilatation
- No parasympathetic vasodilator fibers

Cutaneous vascular reactions: (Triple response)

- **Stimuli:**

Scratching the skin strongly with a blunt object leads to the appearance of the following 3 cutaneous reactions:

- Red line: capillary dilatation due to histamine effect
- Flare phase: Arteriolar dilatation {Local axon reflex}
- Wheal: histamine-induced increase in capillary permeability

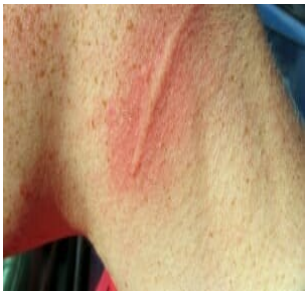


Figure (6): Triple response

Blood flow regulation summary:

Coronary and cerebral circulations	Cutaneous circulation

Vital organs regulated mainly by autoregulation	Non- vital organs, no autoregulation
sympathetic vasomotor tone is minimal.	sympathetic vasomotor tone is maximal.